



# DESIGN AND CONTROL OF ATC FOR SHORTER TIME INTERVAL IN CNC MACHINES

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## ABSTRACT

*This project focuses on the design and control of Automatic Tool Change (ATC) system in CNC machineries to reduce the time interval during tool change process. Here three methods are used in this project, whereas the first method is the set of mathematical logics is used to find the shortest distance in Tool magazine during tool change.*

*The second method is the use of Rotary encoder in the Magazine motor, In the present system the digital input (count sensor) is used to count the pocket movement in the magazine using Cam movement(Fixed position) from one pocket to another pocket, but the time interval between pocket to pocket is more. Hence to reduce this time, rotary encoder is being used to read each pocket positions through high pulse input.*

*The third method is the creating and interfacing the Tool change database in Auto mode during machining, the detailed analysis of these three methods is shown below.*

**Key words:** CNC Machine, ATC, CNC System.

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## 1. INTRODUCTION

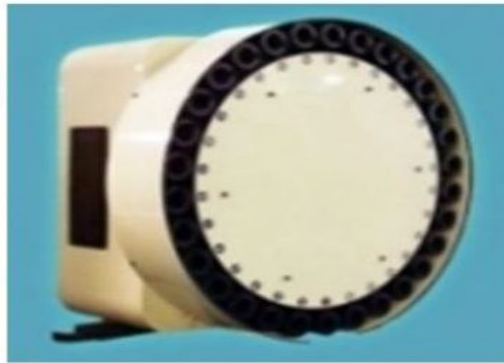
Computer numerical control is the process of manufacturing machined parts using a computerized controller to command motors which drive each machine axis. In order to achieve high precision machining, many efforts have been made to develop more Accurate computerized numerical control (CNC) systems.

CNC systems are commonly used in industrial and commercial applications for its compact size, high power-to-weight ratio, reliability, and low maintenance. CNC System includes a PC, motion board, servo motor drive and motors, spindle drive and

Motor, automatic tool-changer and general I/O card. A tool magazine is an indexable storage used in a machining center to store tools not in use.

The tool magazines available are.

- 1) Rotary Drum type ATC.
- 2) Chain type ATC.
- 3) Turret Head type ATC.



ROTARY DRUM TYPE ATC

**Figure 1** Rotary drum type ATC



CHAIN TYPE TOOL CHANGER

**Figure 2** Chain type ATC



TURRET HEAD TYPE ATC

**Figure 3** Turret head type ATC

## 2. OPERATING PROCEDURE

A common mill feature that reduces cycle times by automatically changing tools between cuts. Automatic tool changers are differentiated by tool-to-tool time and the number of tools they can hold

### 2.1. Working Principle of ATC

The desired tool is collected from one end of the magazine of the spindle arm. At the position of tool change, the empty end of the arm grips the tool in the spindle, removes it, indexes to 180° and inserts the new tool into the spindle.

There is no. of variations on the double arm. It is due to design of arm and variation in the relative movement between the arm and spindle during tool change. Quill type spindles generally move at towards the stationary (after rotation) arm to accept a new tool or replace the existing tool. For non type spindles, the double end arm incorporates an in out motion to insert or extract the tool from the spindle taper. Their functions are;

- 1) Transports the tool magazine during storage.
- 2) Keep the tool clean.
- 3) It avoids the tool change.

Apart from these, the ATC also does the function that, keeps the tracks of tools. This may be done by coding the tools physically either on the tool itself or in the magazine adjacent to the tool, when the pocket is loaded. Alternatively, to use the NC program itself. A tooling instruction sheet is given to the operator with every tape and part setup sheet with the manual data entry system, this problem becomes easy by operator keying Both the tool number and corresponding pocket number.

The NC does the data handling and retrieving tool position and also the reviewing the tool position of the CRT control is possible at any time. When it is time directional magazine clockwise or anti - clockwise to get the proper pocket to its pick point, and gives instruction to the magazine – drive motor.

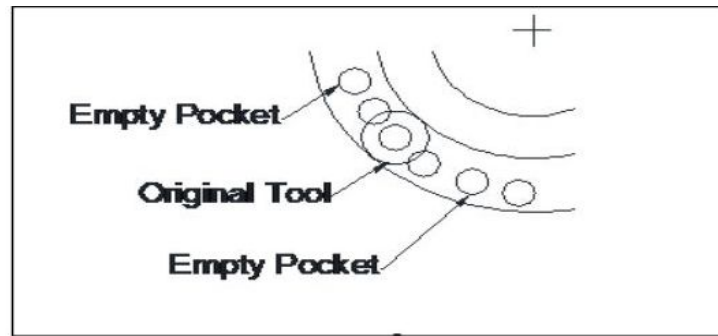
### 2.2. Technical Consideration Influence the ATC

The following technical factor area influenced in the tool change of CNC programming control system. These factors are related mostly related to physical characteristics of cutting tool. They will be

- Maximum tool diameter.
- Maximum tool length.
- Maximum tool weight.

### **2.2.1. Maximum Tool Diameter**

If there is any, necessary to use the maximum size of the tool in the pocket of a tool magazine, then it can be used without any special consideration. But it may affect the adjacent pocket. In this situation, it is necessary to empty the two adjacent pockets of the magazine.



**Figure 4** The adjacent pockets must be empty for a large tool diameter.

Let assume the machine is in a position to hold the tool with a diameter and adjacent pocket diameter is 100mm. If the both adjacent Pockets are emptied then the maximum size of the tool can be increased to 150 mm. But there is a decrease in actual capacity tool placed in the tool magazine.

### **2.2.2. Maximum Tool Length**

The tool length is nothing but the projection of cutting from the spindle gauge line towards the part of the automatic tool changer. If the length of the tool is more, then it is necessary to give more attention to the clearance on Z – axis during tool change. Any physical contact of the tool with a machine or fixture will create undesirable damage and the condition will be highly dangerous. These difficulties can be overcome by an emergency switch on the CNC machine.

### **2.2.3. Maximum Tool Weight**

The tool weight is also one of the important factors to be considered, but it does not make any difference in programming, because most of the tools are lighter weight to compare with recommended weight. The ATC is a large mechanical device therefore it contains limitations. The weight of the tool is always combined weight of cutting tool holder, including collets, screws, pull studs and similar parts.

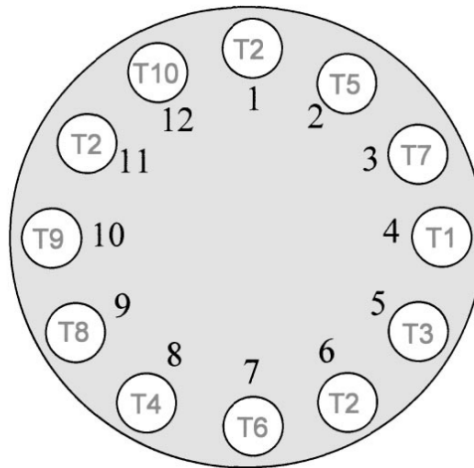
For example, given CNC machining center may have to be recommended tool weight specified about 10 kg. If even a slightly heavier is used 11 kg. The automatic tool changer should not be used over weight at all.

## **3. METHODS TO REDUCE THE TOOL CHANGE TIME INTERVAL**

There are three methods used in this project to reduce the tool change operation time.

- To find the shortest path in the Tool magazine during rotation.
- Using Rotary Encoder in the Magazine motor.
- Creating and interfacing the Tool change database in the Auto Mode during Machining

### 3.1. Algorithm to Find the Shortest Path in Tool Magazine



**Figure 5** A typical tool arrangements on a 12- station ATC

The mathematical equation used to find the shortest path in the tool magazine is follows.

$$Y = T - C$$

Where, Y is the output variable to rotate the magazine in Clockwise or Anticlockwise direction.

T is the user Tool change position input variable

C is the counter variable that counts the indexing pocket position one by one.

The following conditions implies during this process

#### ***For Magazine Clockwise Rotation***

$$1. 1 \leq Y \leq 6$$

$$2. Y < -6$$

#### ***For Magazine Anti Clockwise Rotation***

$$1. 7 \leq Y \leq 12$$

$$2. -6 \leq Y < -1$$

When  $T = C$  no Magazine rotation

### **Real Time Example**

The real time examples are as follows.

#### ***1. When $T=9$ ; $C=1$***

$$Y = T - C \quad Y = 9 - 1$$

$$Y = 8$$

$Y = 8$  satisfies the limit  $7 \leq Y \leq 12$ , so magazine rotates in CCW direction which is the shortest path.

$$\text{Now, } C = 1 + 8 = 9$$

Therefore  $T = C$  in which the

Magazine stop its rotation.

**2. When  $T=12$ ; and now  $C=9$**

$$Y=T-C \quad Y=12-9$$

$$Y=3$$

$Y=3$  satisfies the limit  $1 \leq Y \leq 6$ , so magazine rotates in CW direction which is the shortest path.

$$\text{Now, } C=9+3=12$$

Therefore  $T=C$  in which the Magazine stop its rotation.

**3. When  $T=4$ ; and now  $C=12$**

$$Y=T-C$$

$$Y=4-12$$

$$Y=-8$$

$Y=-8$  satisfies the limit  $Y < -6$ , so magazine rotates in CW direction which is the shortest path.

$$\text{Now, } C=12-8=4$$

Therefore  $T=C$  in which the Magazine stop its rotation.

**4. When  $T=1$ ; and now  $C=4$**

$$Y=T-C \quad Y=1-4$$

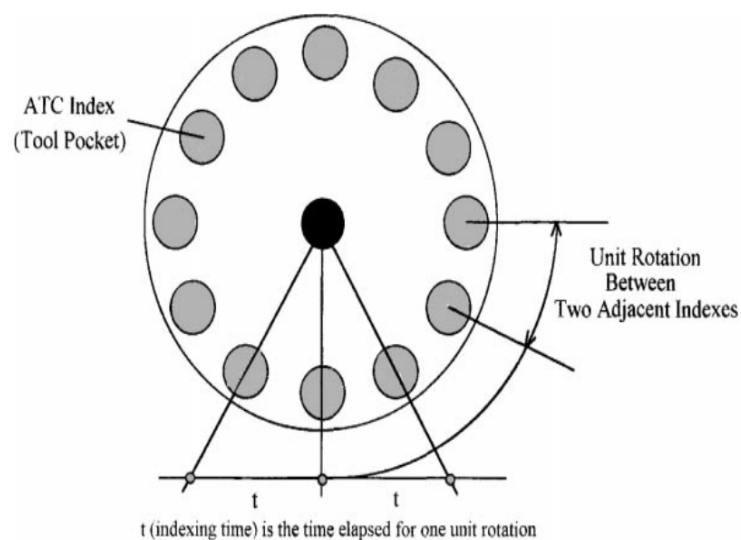
$$Y=-3$$

$Y=-3$  satisfies the limit  $-6 \leq Y \leq -1$ , so magazine rotates in CCW direction which is the shortest path.

$$\text{Now, } C=4-3=1$$

Therefore  $T=C$  in which the Magazine stop its rotation.

**3.2. Using Rotary Encoder in Magazine Motor**



**Figure 7** Turret indexing time

### 3.2.1. Rotary Encoder Working Principle

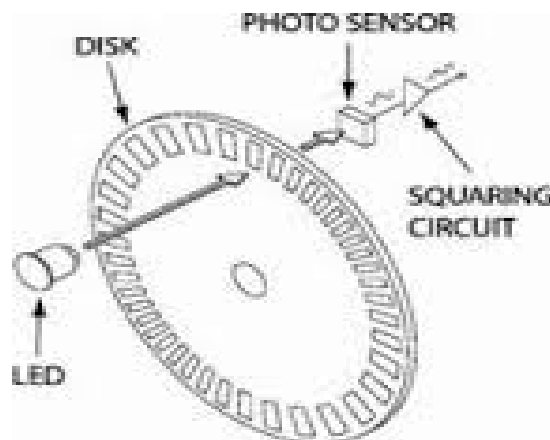
An encoder is a rotational transducer converting an angular movement into a series of electrical digital pulses. If associated to racks or endless screws, these generated pulses can be used to control angular or linear movements. During rotation, electrical signals can be elaborated by numerical controls (CNC), programmable logic controls (PLC), control systems, etc. Main applications of these transducers are: machinery, robots, and motor feedback, measure and control devices.

In encoders the angular movement transduction is based on the photoelectric Scanning principle. The reading system is based on the rotation of the radial graduated disk formed by opaque windows and transparent ones alternated. The system is perpendicularly illuminated by an infrared light source. The light projects the disk image on the receiver's surface which are covered by a grating called collimator having the same disk steps. The receivers transducer the light variation occurring with the disk shifting, converting them into their corresponding electrical variations. Electrical signals raised to generate squared pulses without any interference must be electronically processed.



**Figure 8** Rotary encoder

The reading system is always carried out in differential modality, in order to compare different signals nearly identical but out of phase for 180 electrical degrees. That in order to increase quality and stability of output signals. The reading is designed comparing the difference between the two channels eliminating the disturb note as “shifted common way” because signals are overlapped in equal way



**Figure 9** Encoder disc

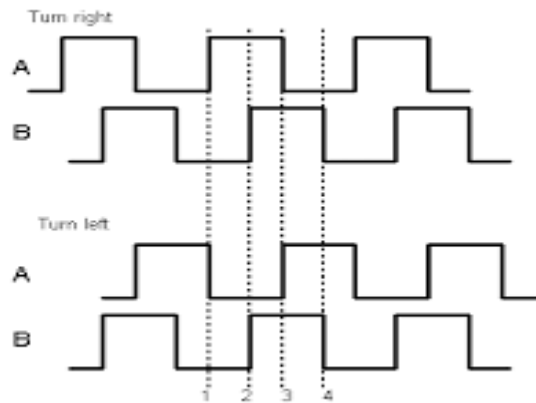


Figure 10 Pulse waveform

### Functional Benefit

By using the encoder in the magazine motor, the following advantages are as follows.

1. The Cam shaft is eliminated, so that the stopping time is eliminated and there is only continuous rotation.
2. The count sensor sometimes misses the count input due to environmental dust or Mis alignment, by using the encoder it can be avoided.
3. The pulses are taken from the encoder for calculation of total pocket positions in the Magazine, by using this value, individual pocket positions are registered in PLC for Tool change operation.
4. By this method of operation, the tool change operation time can be reduced to certain extent.

### 3.3. Creating and Interfacing the Tool Change Database in the Auto Mode

The below diagram is the example part to be machining done with the set of tools in the following order

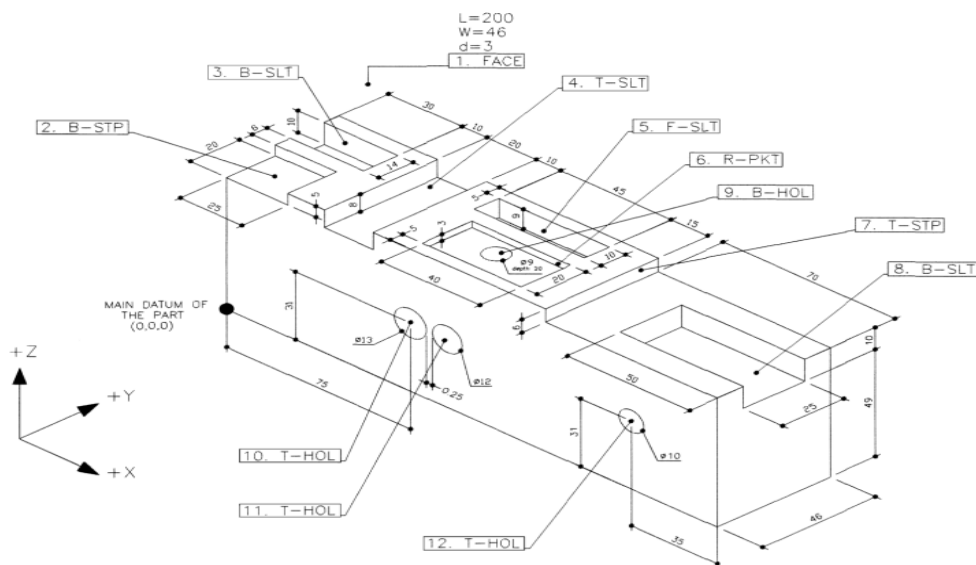
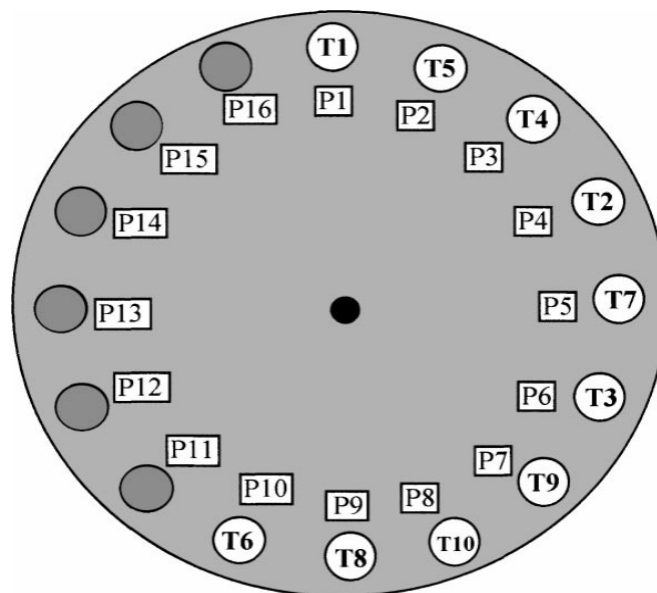


Figure 11 Component CAD diagram



The below table is the order of tool change for machining the example part.

Operation sequence	Operation	Tool Number
O1	FACE MILLING	T5
O2	STEP MILLING	T3
O3	SLOT MILLING	T10
O4	SLOT MILLING	T9
O5	SLOT MILLING	T7
O6	SLOT MILLING	T1
O7	STEP MILLING	T12
O8	POCKET MILLING	T13
O9	CENTRE	T8
DRILLING		
O10	TWIST DRILLING	T14



**Figure 12** Tool positions on the ATC for the example part

#### 4. SEQUENCE CYCLE OF ATC PROCESS

The main component modules of which the ATC systems consist of are:

- Tool magazine;
- Tool transfer mechanism;
- Parking station;
- ATC arm;
- Tool clamp mechanism (spindle).

The automatic tool changer system's role is to provide the machining center spindle with the tool to follow the machining process and to bring the tool which exits the machining process in the tool magazine. Considering that the tools axes from the magazine are normal to the spindle axis, for changing the tool to exit the machining process with a new one, the ATC performs the following movements.

Pos. 1 – ATC arm slides to the tool in the magazine (clamps the tool);

Pos. 2 – ATC arm slides outward (extracts the tool from the magazine);

Pos. 3 – ATC arm slides with the new tool into an Intermediary position;

Pos. 4 – ATC arm slides inward with the new Tool

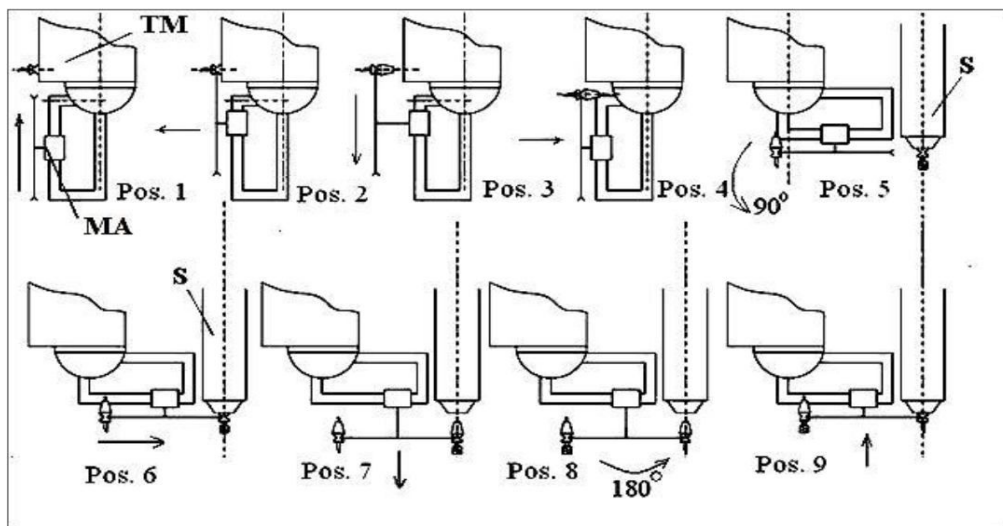
Pos. 5 – ATC arm is rotated with 90° Bringing the new tool in changing position (tool axis is parallel to spindle axis);

Pos. 6 – ATC arm slides to tool in spindle (Clamps the tool);

Pos. 7 – ATC arm slides outward (extracts the tool from spindle);

Pos. 8 – ATC arm rotates with 180° (the tool exchange Takes place);

Pos. 9 – ATC arm slides inward (new tool is Clamped by spindle).



**Figure 13** Tool change sequence

The sequential tool change cycle consists of all the movements performed by the ATC mechanism in order to transfer and change a new tool from the magazine with the tool in the spindle. The total time needed to exchange the tool from the spindle or the tool from the magazine is

$$T_{\text{ATC}} = T_{\text{TM}} + T_{\text{S}} + T_{\text{ATC}} \quad (1)$$

Where:

$\tau_1$  – the indexing time of the tool magazine;

$\tau_2$  – the necessary time for bringing the new Tool by the ATC mechanism into the waiting Position;

$\tau_3$  – the necessary time to exchange the tool

Taken from the tool magazine with the one in the spindle.

The time needed to bring the new tool from the tool magazine in the waiting position by the automatic tool changer arm is given in

$$\tau_4 = \tau_1 + \tau_2 + \tau_3 + \tau_4 + \tau_5 \quad (2)$$

Where:

$\tau_1, \tau_2, \tau_3, \tau_4, \tau_5$ - are the necessary times

For ATC to perform all the movements

Associated to positions P1, P2, P3, P4,

P5; because these movements are performed during the machining process, thus the time needed to bring the tool into the waiting

Position ( $\tau_2$ ) doesn't influence the

Machining process. This means the Machining process being stopped only for the actual tool exchange in spindle

$$\tau_6 = \tau_6 + \tau_7 + \tau_8 + \tau_9$$

Where:

$\tau_6, \tau_7, \tau_8, \tau_9$ - are the necessary times for

ATC to perform all the movements to

Perform the tool exchange in the spindle associated to positions P6, P7, P8, P9; because the auxiliary movements are overlapped with the machining process, the total time for exchanging the tool in the spindle is highly minimized.

#### 4.1. Functional Benefits

- In the existing system in CNC machines, the tool change will run only after the completion of the particular machining process. This will take 4 seconds to 8 seconds.
- The aim of this method is, the next tool will be ready for tool change near the double arm during the machining process, so once the machining is completed only the double arm rotation is indexed to change the tool from Magazine to Spindle.
- A set of tool change database is created for machining the particular component and it is being interfaced in the software to execute only during the AUTO mode.
- It works normally when changed from AUTO to JOG mode.
- By this method, the tool change operation is drastically reduced from normal time of 8 sec to 2 sec.
- Only the double arm rotation indexing time is taken in to account.
- Additionally the implementation of tool database interface in the existing software and the alteration in the PLC logics is to be performed.

## 5. CONCLUSION

The different methods are used in this method to reduce the tool change operation time in CNC machines. Each method has its own advantage and disadvantage in terms of cost factor. Further in future, the selection of existing CNC machines to implement any one of the methods to reduce the cycle time without disturbing the external parameters at the reasonable cost.

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